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A Minerals Availability System Appraisal

By Rodney D. Rosenkranz, Robert L. Davidoff,
and Jim F. Lemons, Jr.

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FOREWORD

The Bureau of Mines Minerals Availability Program is assessing the worldwide availability of nonfuel minerals. The program identifies, collects, compiles, and evaluates information on active, developed, and explored mines and deposits, and on mineral processing plants worldwide. Objectives are to classify domestic and foreign resources, to identify by cost evaluation resources that are reserves, and to prepare analyses of mineral availabilities.

This report is the first of a continuing series of MAS reports to analyze the supply of minerals from domestic and foreign sources. Analysis of supply from other minerals is currently in progress. Questions about the MAS program should be addressed to Director, Division of Minerals Availability, Bureau of Mines, 2401 E Street, NW., Washington, D.C. 20241.

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COPPER AVAILABILITY – DOMESTIC

A Minerals Availability System Appraisal

by

Rodney D. Rosenkranz,[1] Robert L. Davidoff,[2] and Jim F. Lemons, Jr.[2]

ABSTRACT

The Bureau of Mines evaluated the potential supply of primary copper from domestic mines and deposits and found that increases in copper price will be required in order for many domestic deposits to continue production. As part of the study, a tonnage-price relationship was developed indicating the quantity of copper that could be produced economically from known deposits at various copper prices and at various rates of return on the required capital investment. Costs of production are based on estimated capital and operating costs for mining, concentrating, transporting, smelting, and refining. Direct and indirect operating costs, recovery of investment, and return on investment have been included in the smelting and refining costs. Capital and operating costs are calculated in January 1978 dollars, and byproduct credits are based on January 1978 prices.

Known domestic copper mines and deposits contain nearly 92 million metric tons of copper in about 14 billion metric tons of demonstrated mineralized material. These tonnages represent the current domestic copper reserve base. Approximately 74 million metric tons of copper are recoverable from the reserve base using existing technology. Of this quantity, slightly more than 50 million metric tons are economically recoverable assuming a price of $1.00 per pound of copper, credit for the recovery of byproducts, and a 15-percent rate of return on capital investment. Approximately 60 percent of the copper occurs in mines that were producing at the time of the study.

---

[1] Mineral economist.

[2] Metallurgist.

All authors are with the Minerals Availability Field Office, Bureau of Mines, Denver, Colo.

INTRODUCTION

Since World War II, the United States has become a major importer of many mineral commodities basic to an industrialized economy. Prior to World War II, the United States was virtually self-sufficient for its supply of copper and was a major exporter. However, because of world population growth and rising standards of living, competition for world supplies of raw materials has increased steadily during the last 30 years. Therefore, it is necessary that we continually appraise our mineral supply position, noting the conditions affecting the availability of these minerals from domestic sources. Personnel of the Bureau of Mines are continually analyzing the domestic supply and demand of copper to provide data for the formulation of mineral policy.

This study, based on 1978 data, is an evaluation of domestic copper reserves. The objectives follow:

1. To estimate the capital investments and operating costs for appropriate mining and concentrating methods. To determine the operating cost for toll smelting and refining. To estimate the transportation cost of intermediate products to a smelter and refinery.
2. To evaluate the quantity and quality of domestic copper resources in relation to physical, technological, institutional, and other conditions that affect production from each deposit.
3. To perform a cost analysis for each deposit. The results of these analyses indicate the unit prices and associated tonnages of refined copper that can be produced at specific prices.
4. To combine and analyze the price-production relationships for all deposits to show the domestic copper production potential at various metal prices and at various returns on the capital investment.

The data required for this study were developed at Bureau of Mines Field Operations Centers in Denver, Colo., Juneau, Alaska, Pittsburgh, Pa., and Spokane, Wash. Evaluators in these offices derived this information from company data, published data, and trips to the mines and deposits. When necessary, data were calculated by the evaluator. Select data are stored, retrieved, and analyzed in a computerized component of the Minerals Availability System (MAS).

The Bureau of Mines has conducted minerals availability studies in the past that have become quickly obsolete with changes in the influencing factors. Previous Bureau of Mines studies of domestic copper resources were based on 1964 data (3)[3] and 1970 data (2). Results of the current study differ from those of the previous studies because additional cost and resource data have become available.

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[3] Underlined numbers in parentheses refer to items in the list of references preceding the appendix.

ACKNOWLEDGMENTS

The authors wish to thank Harold J. Schroeder, and James H. Jolly of the Bureau of Mines, Division of Nonferrous Metals, for their assistance in determining the properties and associated resource tonnages included in this report. Production and cost data for the deposits analyzed in this study were developed at Bureau of Mines Field Operations Centers in Denver, Colo., Juneau, Alaska, Pittsburgh, Pa., and Spokane, Wash. The Minerals Availability Field Office in Denver performed financial evaluations on the properties and prepared this report.

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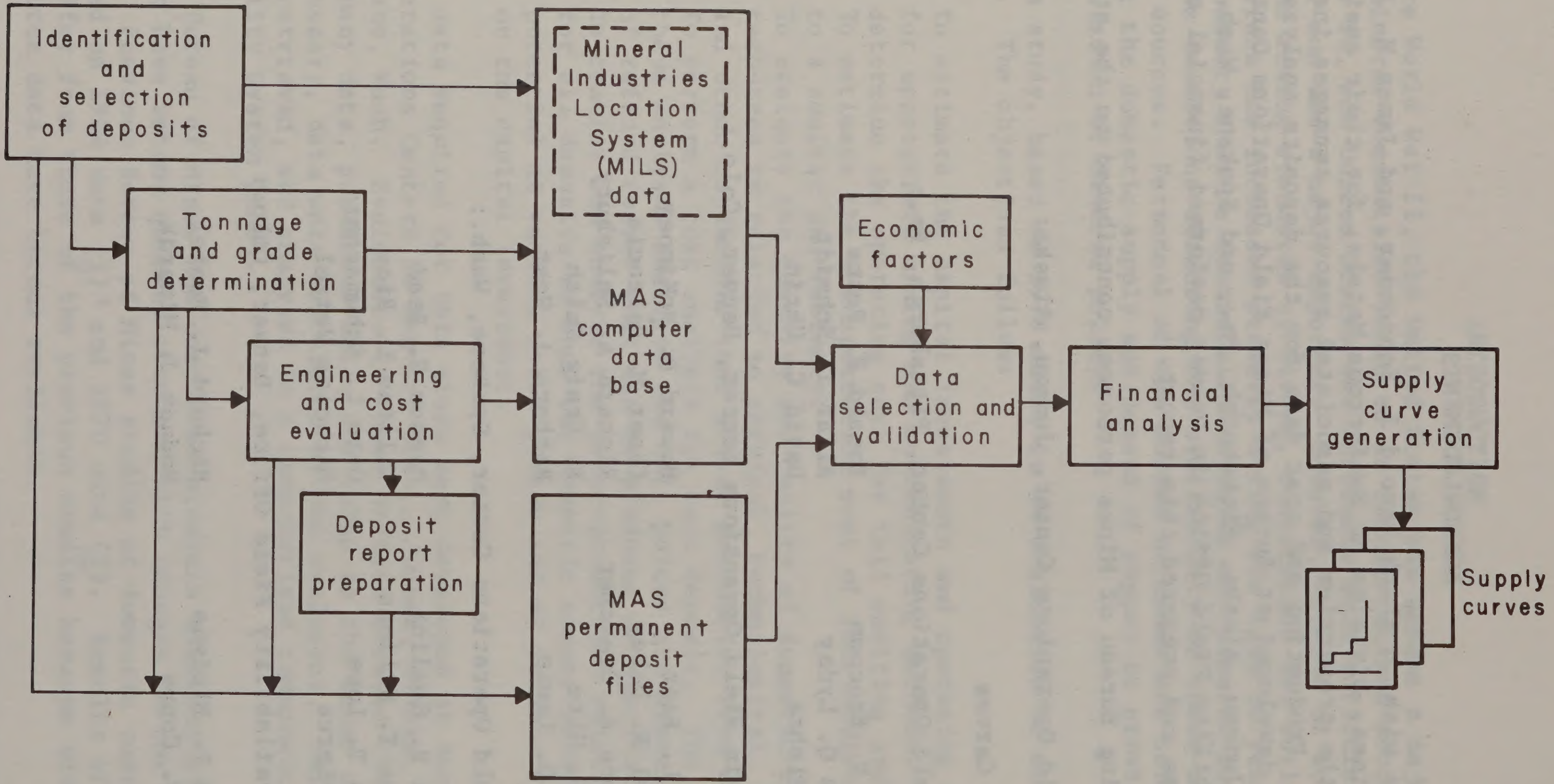
Identification and selection of deposits
Tonnage and grade determination
Engineering and cost evaluation
Deposit report preparation
Mineral Industries Location System (MILS) data
MAS computer data base
MAS permanent deposit files
Economic factors
Data selection and validation
Financial analysis
Supply curve generation
Supply curves

FIGURE 1. - Flow chart of evaluation procedure.

ESTIMATION OF COPPER RESOURCE AND COST DATA

The flow of the MAS evaluation process from deposit identification to development of supply information is illustrated in figure 1. This flowsheet shows the various evaluation stages required to make a determination of the availability of copper from a property.

Seventy-three domestic mines and deposits were selected for analysis in this study. Selection was limited to major, known deposits that had demonstrated copper reserves or resources. Reserves are material that can be mined, processed, and marketed at a profit under the economic and technologic conditions prevailing at the time of the evaluation. Resources are concentrations of naturally occurring solid, liquid, or gaseous materials in or on the Earth's crust in such form that economic extraction of a commodity is currently or potentially feasible. Most reserve and resource tonnage and grade calculations presented in this paper have been computed partly from specific measurements, samples, or production data and partly from projection for a reasonable distance on geologic evidence. Many of these estimates were listed in company publications. Tonnage estimates presented in this report are reported in metric tons. For converting from metric tons to short tons multiply by 1.10231.

Using these reserve and resource estimates, the domestic copper reserve base was established. The reserve base is the in-place portion of demonstrated (measured and indicated) resources from which reserves are estimated. The reserve base includes resources that have the probability of being economically available and is composed of resource categories that are economic (reserves), marginally economic (marginal reserves), and subeconomic (resources). The position of the reserve base within the classification of mineral resources is illustrated in figure 2.

Approximately 40 percent of the properties analyzed were in production at the time of the study. These mines accounted for more than 95 percent of the domestic mine production of copper during 1978. About 60 percent of the copper reserve base occurs in properties that are currently producing.

After a deposit was identified for inclusion in the supply analysis, an evaluation of the property was begun. For mines currently in production, the designed mining and milling production rates and capacities and other available production specifics were adapted for use in this study. For deposits not in production, appropriate mining and concentrating methods, production rates, and other production parameters were assumed. These evaluations were accomplished at Bureau of Mines Field Operations Centers in Denver, Colo., Juneau, Alaska, Pittsburgh, Pa., and Spokane, Wash.

Information on the average grades, ore tonnages, and different physical characteristics affecting production from domestic copper deposits was obtained from numerous sources, including Bureau of Mines and Geological Survey publications, professional journals, industry publications, annual reports, company 10K reports and prospectuses filed with the Securities and Exchange Commission, and data made available to the Bureau of Mines by private companies. The personal knowledge and judgments of Bureau of Mines engineers were utilized in many cases.

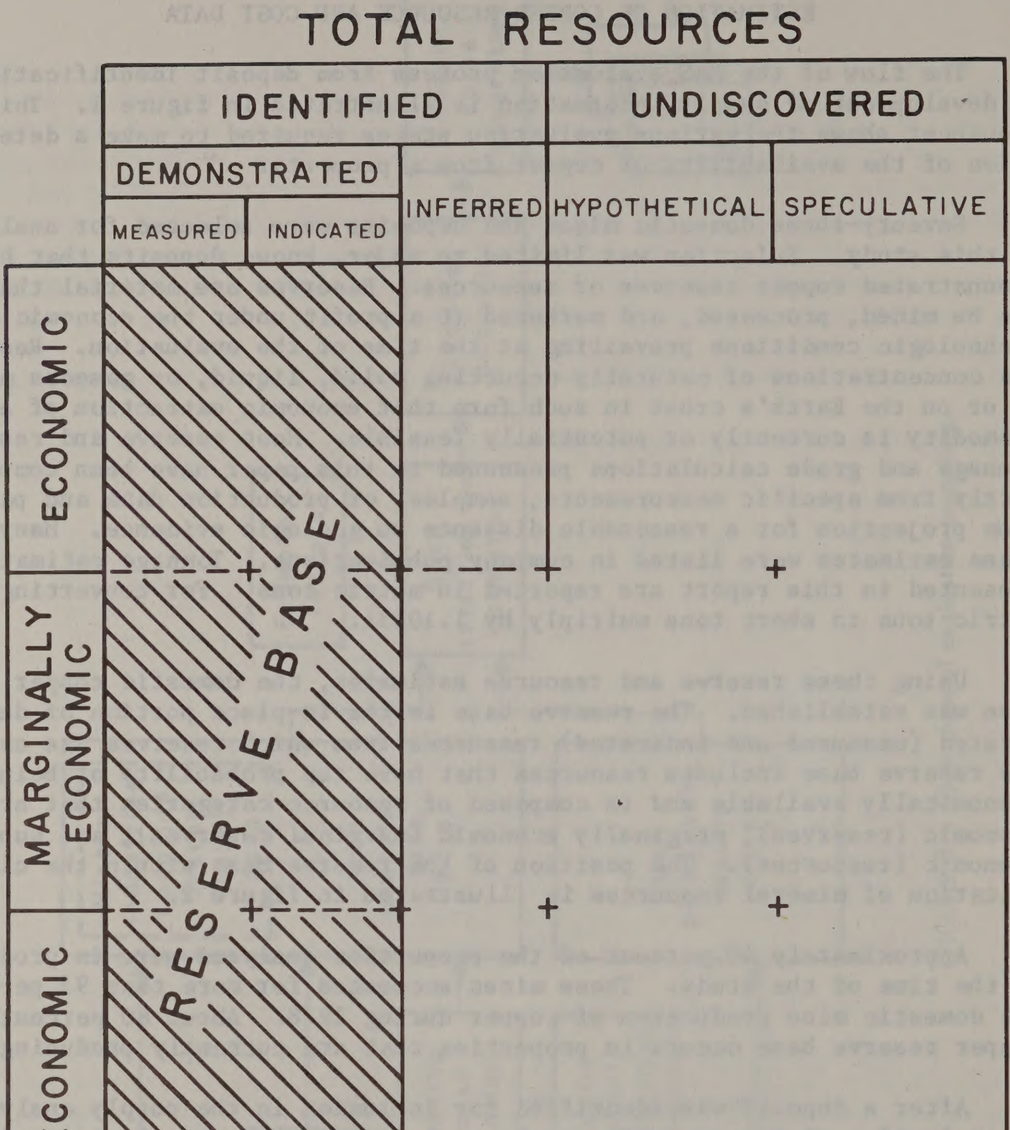

FIGURE 2. - Classification of mineral resources.

Capital expenditures were calculated for exploration, acquisition, development, mine equipment, and for constructing and equipping the concentrating plant. Investments were included for working capital and for replacement of worn equipment. Operating costs for mining and concentrating include direct and indirect operating costs, taxes, insurance, transportation, and royalty. Costs for smelting and refining include direct and indirect operating costs, taxes, insurance, recovery of investment, and return on investment.

TABLE 1. - Example of deposit information required for financial evaluation of a copper property

Category description and units	Year of occurrence		Category value
	Beginning	Ending	
Exploration....................$1,000	1978	1979	$470
Land acquisition...............$1,000	1980	1980	$538
Mining preparation.............$1,000	1979	1980	$1,791
Mine plant.....................$1,000	1979	1980	$898
Mine equipment.................$1,000	1979	1979	$2,286
Do.........................$1,000	1980	1980	$2,846
Mine equipment reinvestment....$1,000	1984	1984	$604
Do.........................$1,000	1985	1985	$632
Do.........................$1,000	1986	1986	$955
Do.........................$1,000	1987	1987	$2,292
Do.........................$1,000	1990	1990	$1,198
Do.........................$1,000	1991	1991	$1,244
Mill plant and equipment.......$1,000	1979	1980	$18,703
Working capital................$1,000	1981	1981	$2,366
Mine operating cost..........$/MT ore	1981	1995	$1.450
Mill operating cost..........$/MT ore	1981	1995	$1.700
Ore mined per year........metric tons	1981	1995	4,520,000
Copper:			
Feed grade...............percent Cu	1981	1995	0.43
Mill recovery..............percent	1981	1995	93.00
Concentrate grade........percent Cu	1981	1995	28.00
Smelter recovery...........percent	1981	1995	98.00
Smelter grade............percent Cu	1981	1995	98.00
Refinery recovery..........percent	1981	1995	99.90
Smelter operating cost....$/MT conc	1981	1995	$93.00
Refinery operating cost ....$/MT blister	1981	1995	$192.00
Transportation to smelter.$/MT conc	1981	1995	$6.90
Transportation to refinery ....$/MT blister	1981	1995	$9.90
Molybdenum:			
Feed grade...............percent Mo	1981	1995	0.013
Mill recovery..............percent	1981	1995	63.00
Concentrate grade........percent Mo	1981	1995	50.00
Price.......................$/pound	1981	1995	$4.01
Gold:			
Feed grade..........troy ounces/MT	1981	1995	0.003
Mill recovery..............percent	1981	1995	90.00
Concentrate grade....troy ounces/MT	1981	1995	0.20
Smelter recovery...........percent	1981	1995	95.00
Selling price..........$/troy ounce	1981	1995	$173.69
Silver:			
Feed grade..........troy ounces/MT	1981	1995	0.06
Mill recovery..............percent	1981	1995	90.00
Concentrate grade....troy ounces/MT	1981	1995	3.53
Smelter recovery...........percent	1981	1995	95.00
Selling price..........$/troy ounce	1981	1995	$4.93

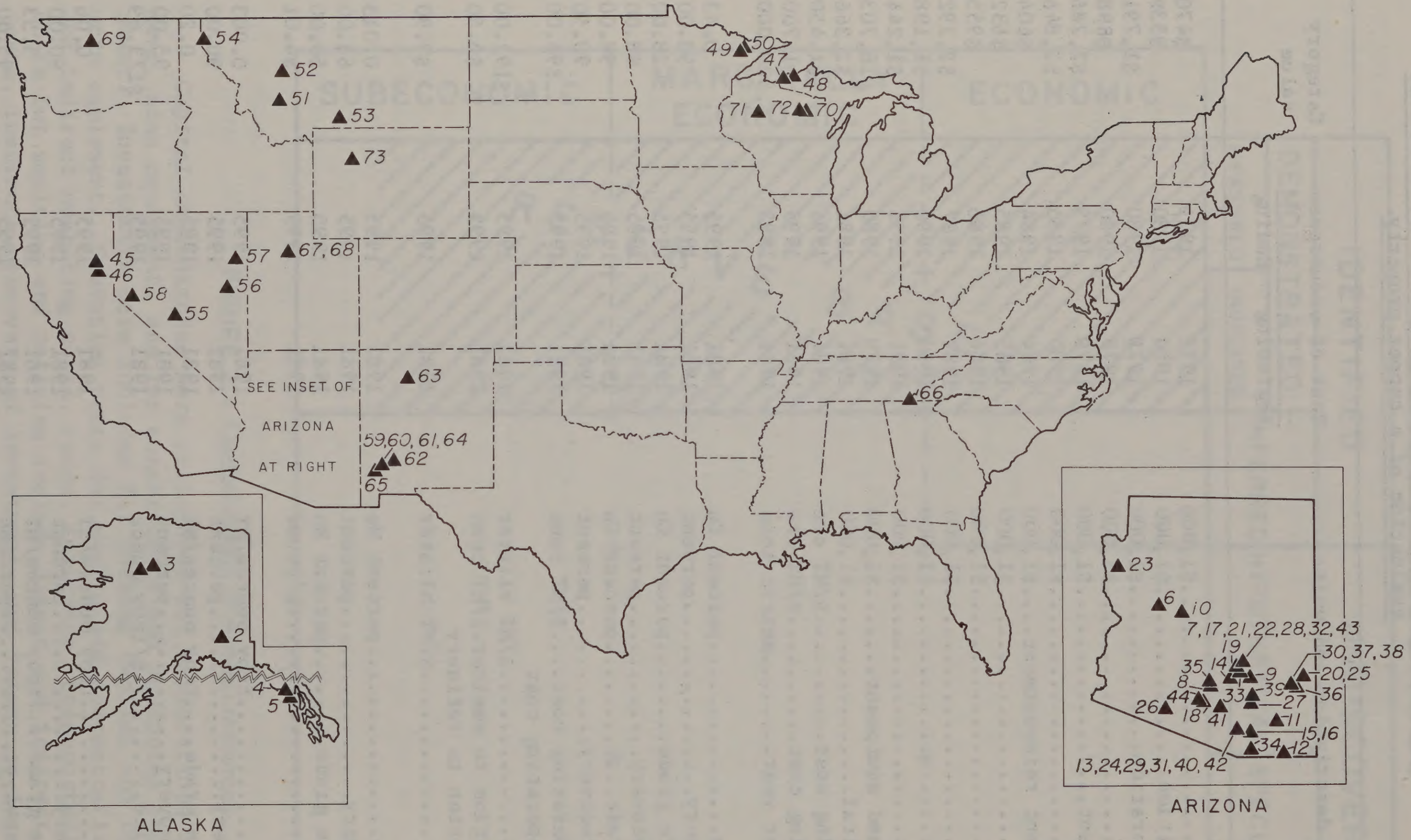

FIGURE 3. - Location of domestic copper properties. (Numbers refer to the map index numbers in table 3.)

A financial evaluation for each property was then performed. This was accomplished by personnel in the Minerals Availability Field Office in Denver, Colo. Using the data developed by the Field Operations Centers, files were built for computerized analysis of each property. Table 1 is an example of the type of data required for financial analysis.

For properties not now in production, all capital costs were converted to January 1978 dollars. For mines currently producing, the undepreciated capital investment remaining in January 1978 was calculated. All reinvestment, operating, and transportation costs were converted to January 1978 dollars. Analysis was then performed, by computer, to determine the copper price necessary for each deposit to receive 0- and 15-percent rates of return. (At a 0-percent rate of return, the deposit would recover its investment but would make no profit on the investment. At a 15-percent rate of return, the investment would be recovered and a 15-percent profit would be made on the investment.) Individual deposit tonnage-price data were then aggregated to construct the supply curves presented in this study. Analyses were conducted in terms of constant dollars. No escalation of either costs or prices was included since it was assumed that any increase in cost would be offset by an increase in price. Prices used for byproducts and coproducts are shown in table 2.

Table 3 presents individual deposit information, by State, and figure 3 shows the location of the properties. The numbers on the map refer to the deposit's map index number shown on table 3.

Ownership and control data for each property are presented in table A-1 in the appendix.

TABLE 2. - Byproduct and coproduct commodity prices

Commodity	Price, January 1978
Cobalt [1]	$6.40 per pound
Gold [1]	173.69 per troy ounce
Iron [2]	36.42 per metric ton of pellets
Lead [1]	0.33 per pound
Molybdenum [3]	4.01 per pound
Nickel [1]	2.08 per pound
Palladium [3]	60.00 per troy ounce
Platinum [3]	188.33 per troy ounce
Selenium [2]	10.50 per pound
Silver [1]	4.93 per troy ounce
Sulfur [2]	38.42 per metric ton acid
Tungsten [2]	9.55 per pound
Zinc [1]	0.31 per pound

---

[1] Bureau of Mines. Minerals and Materials--a Monthly Survey. April 1978.

[2] Derived by MAS from Bureau of Mines, company, and published data.

[3] Engineering and Mining Journal, January and February 1978.

TABLE 3. - Property status, mining method, and reserve base data[1]

(Prd - producer: Dev - developed deposit: Exp - explored deposit: Ppd - past producer: OP - open pit: UG - underground: L - leach: W - withheld to avoid disclosing individual company confidential data; included in "other properties:" NA - not available: NAp - not applicable.)

Property name	Map index No.[2]	Status[3]	Mining method	Grade[4] (percent copper)	Reserve base (thousand metric tons)	
					Mineralized material[5]	Contained copper
Alaska:						
Arctic Camp.......	1	Exp	OP/UG	4.00	30,840	1,234
Bond Creek Orange Hill.....	2	Exp	OP	W	W	W
Bornite...........	3	Exp	UG	5.30	12,000	636
Brady Glacier.....	4	Exp	UG	W	W	W
Yakobi Island.....	5	Exp	OP	W	W	W
Arizona:						
Bagdad............	6	Prd	OP	.49	263,040	1,289
		Prd	OP	.35	19,050	67
Bluebird..........	7	Prd	L	.49	58,900	289
Casa Grande.......	8	Exp	UG	1.00	317,460	3,175
Christmas.........	9	Ppd	OP	.54	14,000	76
		Exp	OP	.43	9,000	39
		Exp	UG	1.59	31,130	495
Copper Basin......	10	Exp	OP	.55	158,730	873
Cyprus Johnson Camp............	11	Prd	L	.85	20,000	170
Dubacher Canyon...	12	Exp	L	.80	18,140	145
Esperanza.........	13	Ppd	OP	.42	19,820	83
Florence Conoco...	14	Exp	OP	.39	453,590	1,769
		Exp	L	.32	226,800	726
Helvetia East.....	15	Exp	OP	.54	305,670	1,651
		Exp	L	.55	19,950	110
Helvetia West.....	16	Exp	OP	.78	12,470	97
Inspiration Area..	17	Prd	OP	.56	166,120	930
Lakeshore.........	18	Ppd	UG	.70	239,000	1,664
		Ppd	UG	.71	186,000	1,312
Magma (Superior)..	19	Prd	UG	4.50	7,260	327
Metcalf...........	20	Prd	OP	.78	353,110	2,754
Miami East........	21	Dev	UG	1.95	49,890	973
Miami Leach.......	22	Prd	L	W	W	W
Mineral Park......	23	Prd	OP	.30	44,940	135

See footnotes at end of table.

TABLE 3. - Property status, mining method, and reserve base data[1]

Property name	Map index No.[2]	Status[3]	Mining method	Grade[4] (percent copper)	Reserve base (thousand metric tons) Mineralized material[5]	Reserve base (thousand metric tons) Contained copper
Arizona - continued:						
Mission San Xavier	24	Prd	OP	.60	246,120	1,477
Morenci	25	Prd	OP	.81	555,010	4,496
New Cornelia (Ajo)	26	Prd	OP	0.66	93,420	617
Oracle Ridge	27	Dev	UG	2.28	10,250	234
Ox Hide	28	Prd	L	.29	36,100	103
Palo Verde	29	Prd	OP	.63	141,950	894
Peacock	30	Ppd	OP	.50	18,140	91
Pima	31	Prd	OP	.48	132,430	636
Pinto Valley	32	Prd	OP	.45	272,000	1,224
		Exp	OP	.34	136,000	462
Ray	33	Prd	OP	.79	595,430	4,704
Red Mountain	34	Exp	UG	.71	100,000	710
Sacaton, West	35	Prd	OP	.70	19,170	134
East	35	Exp	UG	1.25	13,510	169
Safford Inspiration (Sanchez)	36	Dev	OP	.40	181,400	726
Safford Kennecott	37	Dev	L	.50	453,600	2,268
Safford Phelps Dodge	38	Dev	UG	.72	362,810	2,612
San Manuel	39	Prd	UG	.70	416,000	2,912
Kalamazoo	39	Exp	UG	.72	512,500	3,690
Sierrita	40	Prd	OP	.32	417,090	1,335
Silver Bell	41	Prd	OP	.66	23,640	156
Twin Buttes	42	Prd	OP	.67	298,410	1,999
		Prd	OP	1.10	51,700	569
Van Dyke	43	Exp	L	.50	90,700	454
Vekol Hills	44	Exp	OP	.54	95,000	513
California:						
Lights Creek	45	Exp	OP	W	W	W
Walker	46	Ppd	UG	W	W	W
Michigan:						
Presque Isle	47	Exp	UG	1.27	95,240	1,210
White Pine	48	Prd	UG	1.24	332,240	4,120
		Prd	UG	1.35	29,030	392

See footnotes at end of table.

TABLE 3. - Property status, mining method, and reserve base data[1]

Property name	Map index No.[2]	Status[3]	Mining method	Grade[4] (percent copper)	Reserve base (thousand metric tons)	
					Mineralized material[5]	Contained copper
Minnesota:						
Minnamax..........	49	Exp	UG	W	W	W
Ely Spruce........	50	Exp	OP	W	W	W
Montana:						
Butte.............	51	Prd	OP	W	W	W
		Exp	UG	W	W	W
Heddleston........	52	Exp	OP	0.48	84,350	405
Stillwater........	53	Exp	OP	.25	136,960	342
Troy..............	54	Dev	UG	.74	58,060	430
Nevada:						
Hall..............	55	Exp	OP	W	W	W
New Ruth..........	56	Ppd	OP	.79	21,530	170
		Ppd	L	.20	NA	NA
Victoria..........	57	Ppd	UG	W	W	W
Yerington.........	58	Ppd	OP	W	W	W
New Mexico:						
Chino.............	59	Prd	OP	W	W	W
Continental Underground ...	60	Prd	UG	2.06	17,050	351
Continental Surface........	61	Prd	OP	.86	16,420	141
Hillsboro (Copper Flat)..	62	Exp	OP	W	W	W
Nacimiento........	63	Ppd	L	.67	6,740	45
Pinos Altos.......	64	Exp	OP	2.00	7,000	140
Tyrone............	65	Prd	OP	.82	273,380	2,242
		Prd	L	.32	NA	NA
Tennessee:						
Copperhill	66	Prd	UG/OP	W	W	W
Utah:						
Bingham...........	67	Prd	OP	.70	1,396,800	9,778
Carr Fork.........	68	Dev	UG	1.84	55,510	1,021

See footnotes at end of table.

TABLE 3. - Property status, mining method, and reserve base data[1]

Property name	Map index No.[2]	Status[3]	Mining method	Grade[4] (percent copper)	Reserve base (thousand metric tons) Mineralized material[5]	Reserve base (thousand metric tons) Contained copper
Washington:						
Sunrise..........	69	Ppd	UG	W	W	W
Wisconsin:						
Crandon..........	70	Exp	UG	W	W	W
Flambeau.........	71	Exp	OP	5.11	2,590	132
		Exp	UG	3.02	2,850	86
Pelican River....	72	Exp	UG	1.00	1,450	15
Wyoming:						
Kirwin...........	73	Exp	OP	.75	63,500	476
Other properties...	NAp	NAp	NAp	NAp	3,018,920	15,960
Total......	NAp	NAp	NAp	.66	13,928,910	91,660

---

[1] Additional property information is given in table A-1.

[2] Map index numbers refer to numbers on figure 3.

[3] Status as of February 1979. Producing properties that have additional ore bodies with developed or explored status have been labeled as such.

[4] Units of grade are in weight-percent copper; copper grade from published sources.

[5] Demonstrated (measured + indicated) estimates from published sources.

SUPPLY OF COPPER FROM DOMESTIC DEPOSITS

General

Reserve and resource tonnage and grade estimates presented in this study are based on the demonstrated resources for each deposit. As illustrated in figure 2, demonstrated resources include both measured and indicated reserves and resources. The reserve base, established to estimate copper reserves and resources, is that portion of demonstrated resources that have a probability of economic availability. For 1978, the domestic copper reserve base is estimated to be 92 million metric tons of copper. Of this amount, an estimated 56 million metric tons occur in the reserves and resources of mines that were producing at the time of the study, and 36 million metric tons occur in undeveloped deposits and closed mines.

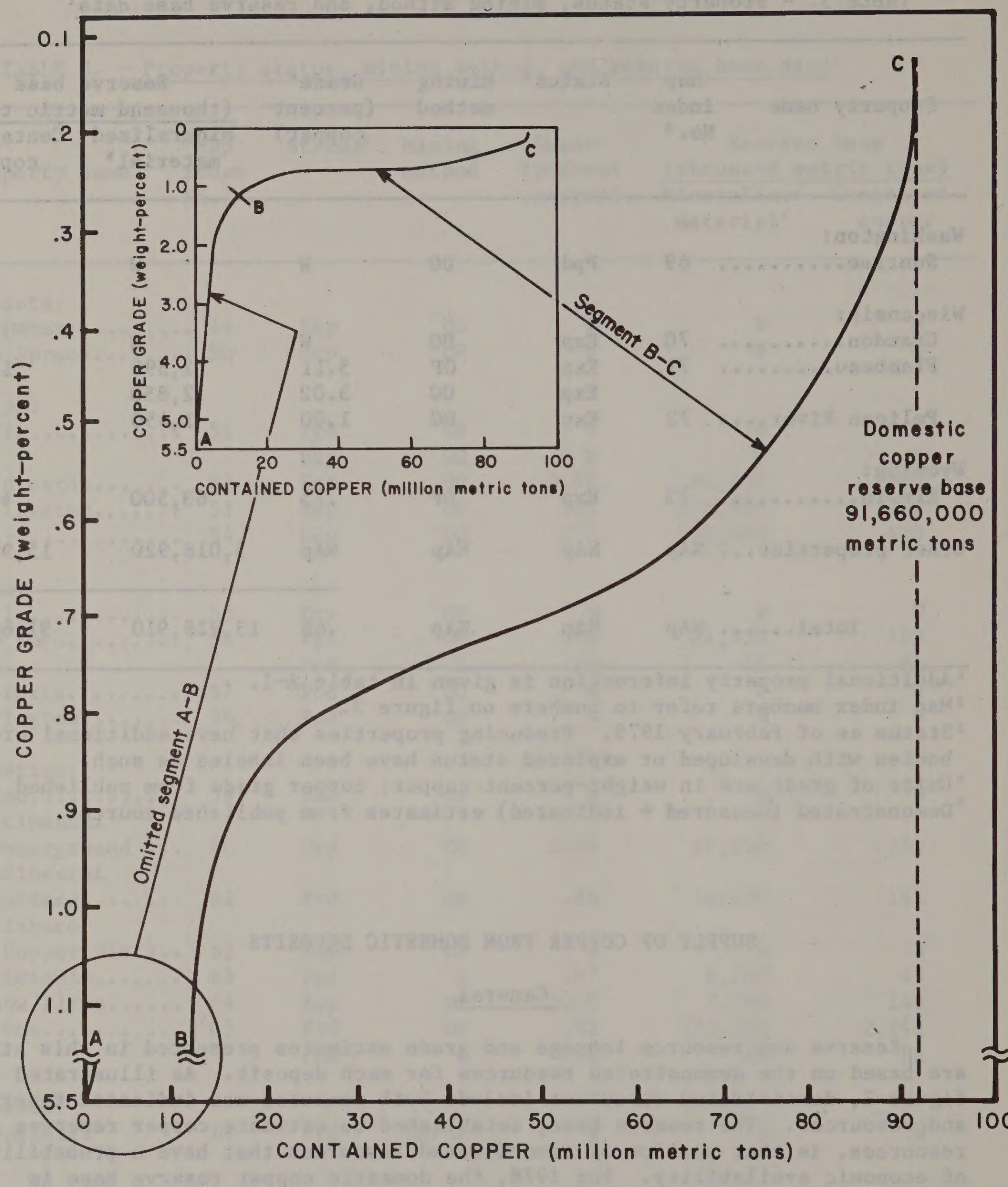

FIGURE 4. - Copper contained in domestic deposits at various copper ore grades.

As exploration and development yield a better knowledge of grades and tonnages, portions of the material may be reclassified. Historically, domestic resources that can be produced economically have increased annually because of exploration and technologic improvements that enable the mining of lower grade material or the processing of material previously considered waste. Production from some deposits included in the study may be limited by environmental constraints.

The domestic copper reserve base was derived by multiplying the resources of each deposit by the associated copper grade. Copper contained at various copper grades is illustrated in figure 4. Copper from some waste-leaching operations was not included in the reserve base because of low recovery factors and difficulties in estimating waste tonnages.

Supply curves have been developed to illustrate total and annual domestic resources. These curves show the quantity of copper that is recoverable using current technology after all mining and processing losses are considered. Approximately 81 percent of the domestic copper reserve base is recoverable using current technology.

Total Recoverable Copper

Not all of the copper contained in an ore body can actually be recovered. Some ore may not be recoverable because of the mining method used. Other losses occur as the ore is processed through the concentrating, smelting, and refining stages. Recoveries vary widely from operation to operation. An in situ leach operation may recover only 30 percent of the contained copper, while a sulfide float operation may recover as much as 95 percent.

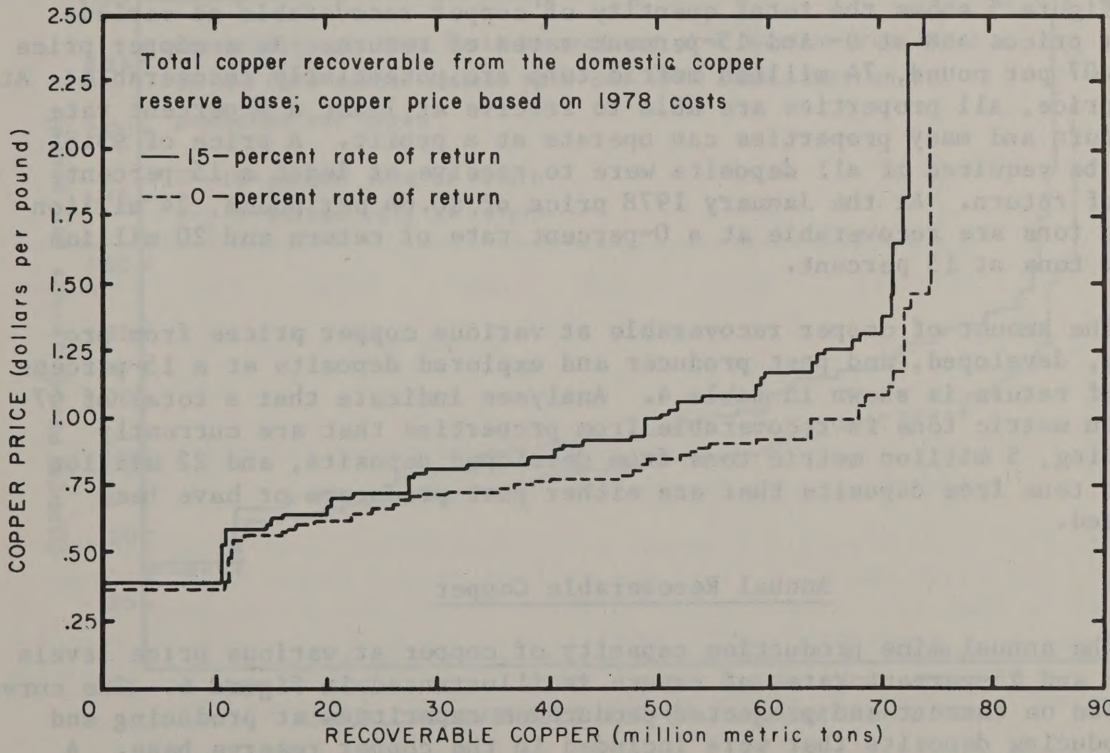

FIGURE 5. - Domestic copper reserve available at various copper prices.

TABLE 4. - Total recoverable copper available from producing, developed, past producer and explored deposits at various copper prices and at a 15-percent rate of return
(thousand metric tons)

Copper price (cents per pound)	Producing deposits[1]	Developed deposits	Past producer and explored deposits	Cumulative
Less than 50....	10,398	0	0	10,398
50 - 59....	4,283	0	185	14,866
60 - 69....	5,323	278	0	20,467
70 - 79....	7,061	0	397	27,925
80 - 89....	10,745	427	2,149	41,246
90 - 99....	6,028	0	1,421	48,695
100 - 124....	2,869	4,049	9,328	64,941
More than 124....	0	488	8,882	74,311
Total........	46,707	5,242	22,362	74,311

[1] Includes deposits that may be temporarily inactive.

Figure 5 shows the total quantity of copper recoverable at various copper prices and at 0- and 15-percent rates of return. At a copper price of $2.07 per pound, 74 million metric tons are potentially recoverable. At this price, all properties are able to receive at least a 0-percent rate of return and many properties can operate at a profit. A price of $3.81 would be required if all deposits were to receive at least a 15-percent rate of return. At the January 1978 price of $0.64 per pound, 24 million metric tons are recoverable at a 0-percent rate of return and 20 million metric tons at 15 percent.

The amount of copper recoverable at various copper prices from producing, developed, and past producer and explored deposits at a 15-percent rate of return is shown in table 4. Analyses indicate that a total of 47 million metric tons is recoverable from properties that are currently producing, 5 million metric tons from developed deposits, and 22 million metric tons from deposits that are either past producers or have been explored.

Annual Recoverable Copper

The annual mine production capacity of copper at various price levels and 0- and 15-percent rates of return is illustrated in figure 6. The curve is based on current and projected production capacities at producing and nonproducing deposits that were included in the copper reserve base. A copper price of $2.07 per pound would be required for all properties to receive at least a 0-percent rate of return and supply the maximum annual production of 2.8 million metric tons. At a copper price of $3.81 all properties would receive at least a 15-percent rate of return. The expected annual production of recoverable copper at a price of $0.75 could be 1.6 million and 1.0 million metric tons at 0- and 15-percent rates of return, respectively. These annual tonnage data indicate only the potential amount of copper that could be produced at a specific price for any given year. They do not indicate the duration of production or the desirability of actually supplying this annual production capacity. The curve does not consider increased annual production due to exploration and technologic improvements that enable the mining of lower grade material or the processing of material previously considered waste.

It should be noted that an increase in production cannot be obtained immediately by increasing the price. The time required to increase production depends on factors such as the relative location of the deposit and the necessity for exploration, development, and plant construction. Other time delays result because overlying mineralized material of significantly different grade or mineral characteristics, requiring a different mining method, must be removed prior to mining underlying material. Figures 7, 8, and 9 indicate annual production schedules when these time delays are considered.

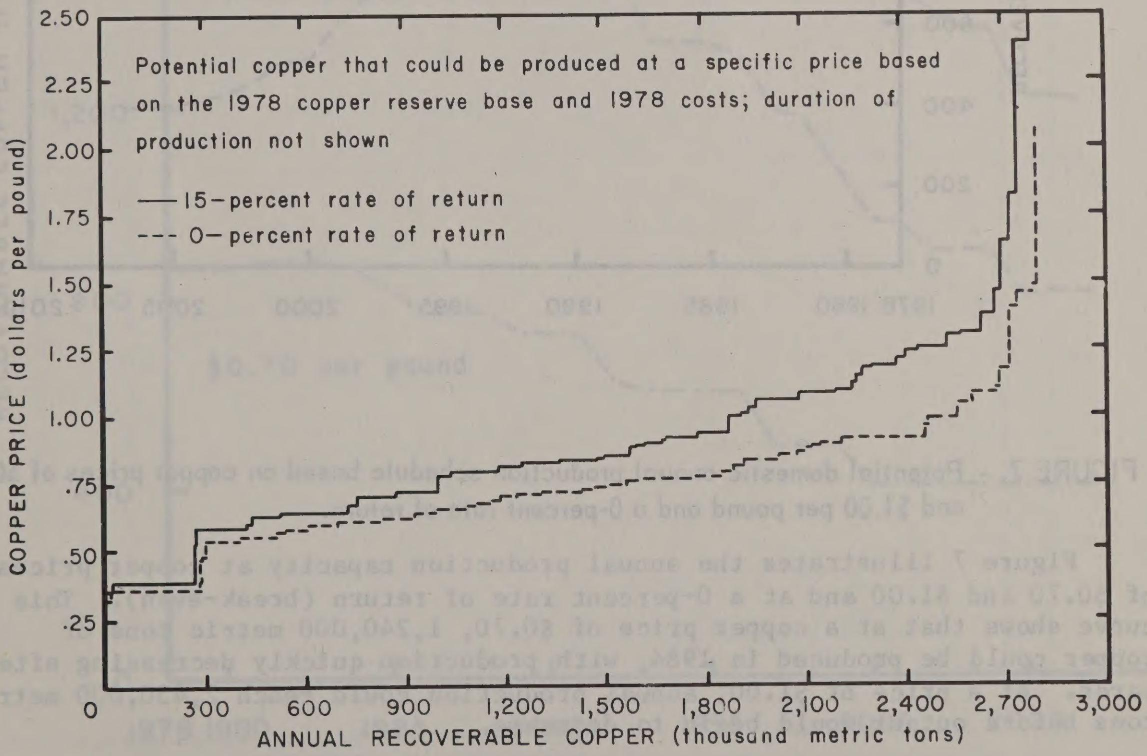

FIGURE 6. - Potential annual domestic production at various copper prices.

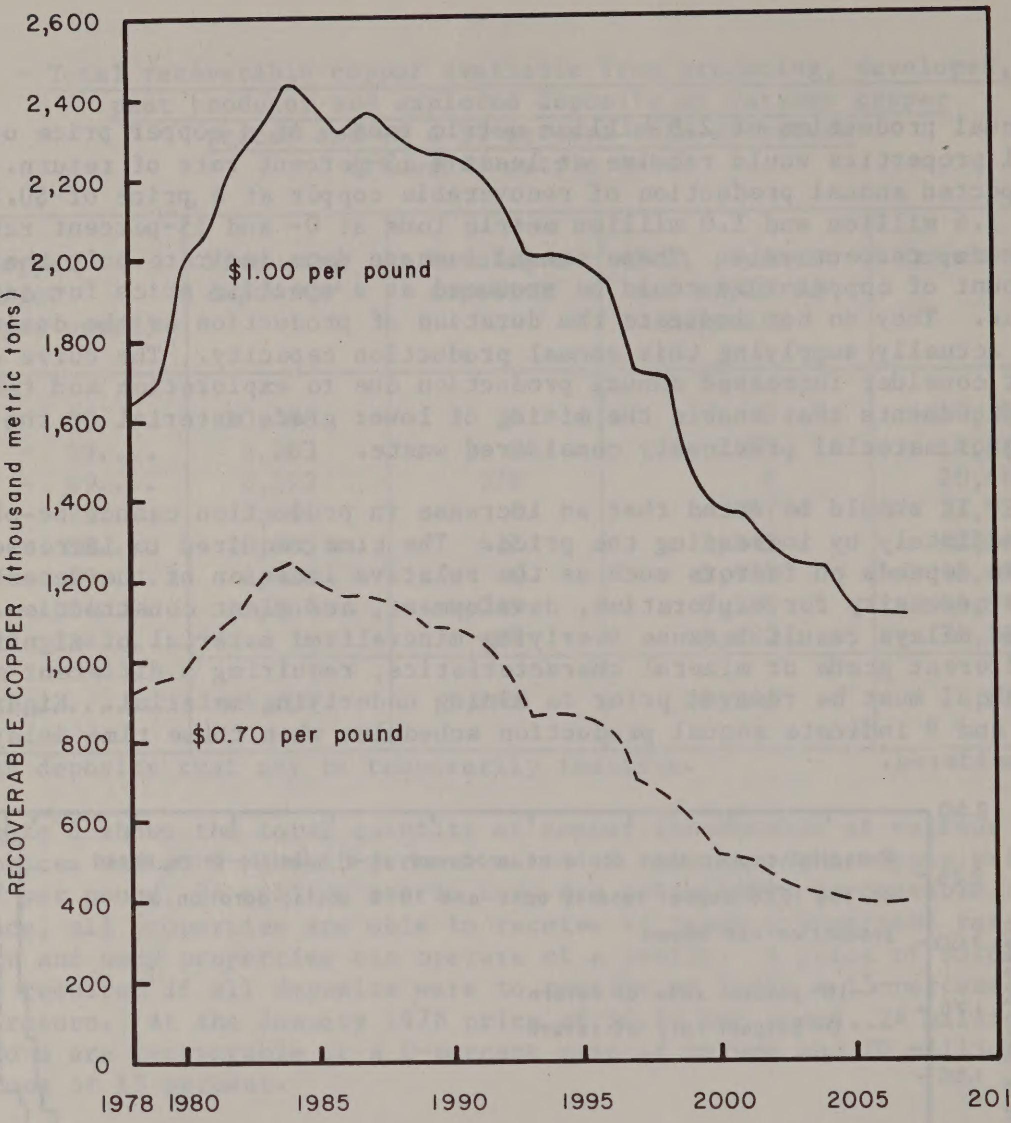

FIGURE 7. - Potential domestic annual production schedule based on copper prices of $0.70 and $1.00 per pound and a 0-percent rate of return.

Figure 7 illustrates the annual production capacity at copper prices of $0.70 and $1.00 and at a 0-percent rate of return (break-even). This curve shows that at a copper price of $0.70, 1,240,000 metric tons of copper could be produced in 1984, with production quickly decreasing afterwards. At a price of $1.00, annual production could reach 2,450,000 metric tons before output would begin to decrease.

Figure 8 shows the annual mine production capacity of copper at prices of $0.70, $1.00, and $2.00 per pound and at a 15-percent rate of return. A maximum of 885,000 metric tons is available annually at $0.70 per pound.

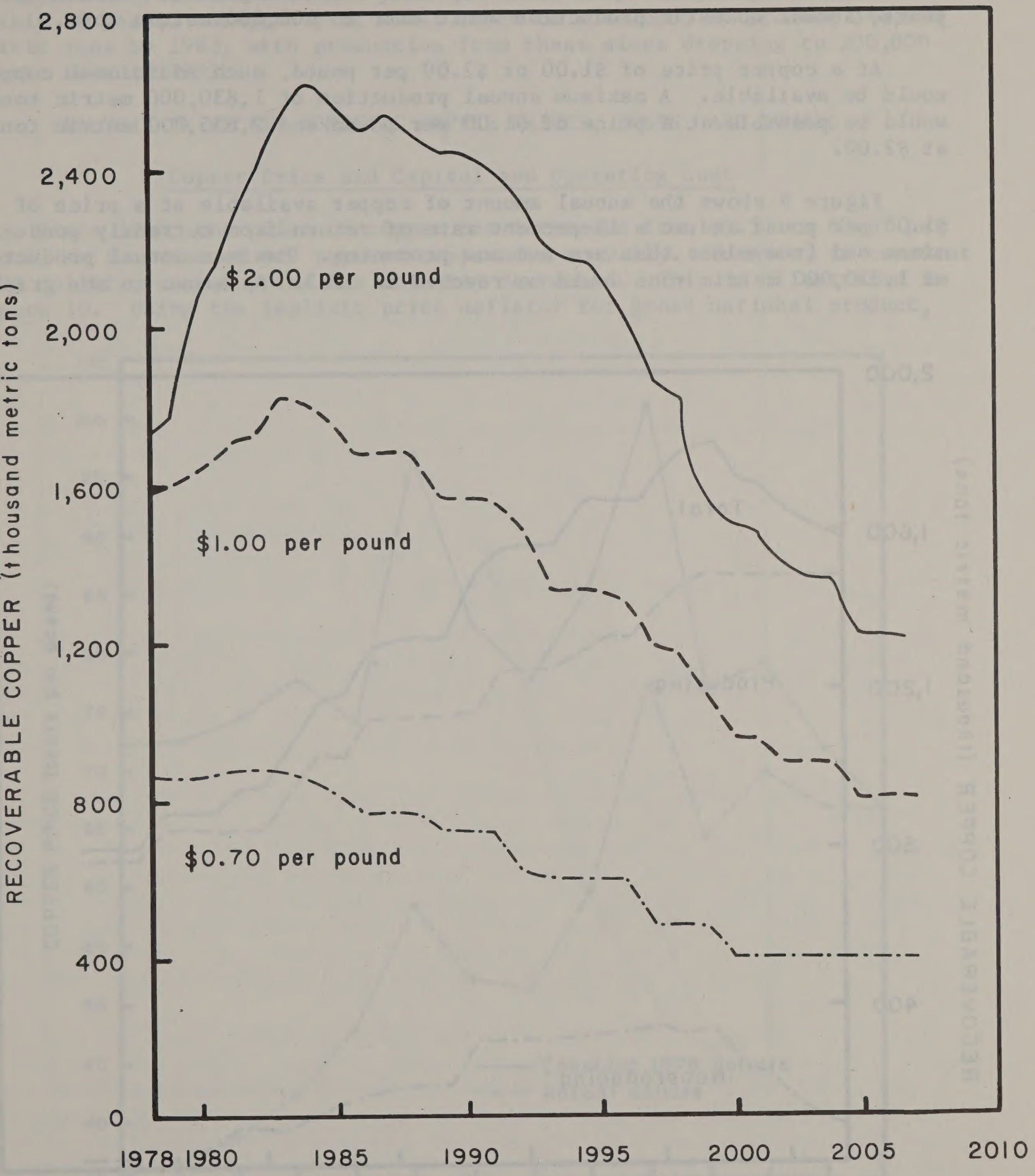

FIGURE 8. - Potential domestic annual production schedule at various copper prices and a 15-percent rate of return.

If copper price were to remain constant at this price, annual production would begin to decrease in 1984 as deposits become depleted. Within 30 years, annual domestic production would drop to 400,000 metric tons.

At a copper price of $1.00 or $2.00 per pound, much additional copper would be available. A maximum annual production of 1,830,000 metric tons would be possible at a price of $1.00 per pound and 2,635,000 metric tons at $2.00.

Figure 9 shows the annual amount of copper available at a price of $1.00 per pound and at a 15-percent rate of return from currently producing mines and from mines that are not now producing. Maximum annual production of 1,830,000 metric tons would be reached in 1983. As shown on the graph,

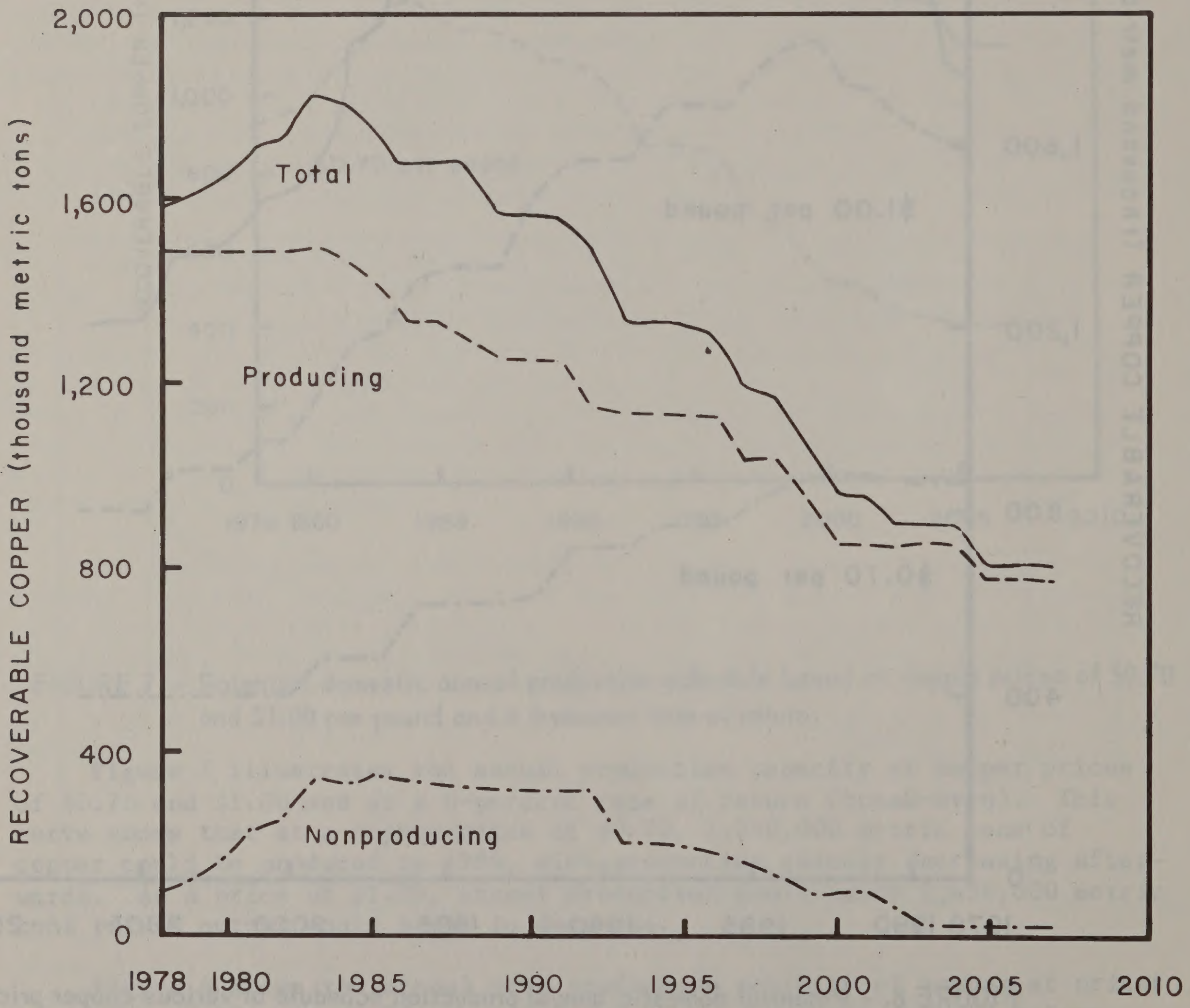

FIGURE 9. - Present and potential annual domestic production schedule based on a copper price of $1.00 per pound and a 15-percent rate of return.

at this price most of the copper is available from mines that are currently producing. Annual production from producing mines could reach a maximum of 1,485,000 metric tons within 1 year but would drop to 1,040,000 metric tons within 20 years. Nonproducing mines could be developed to produce 340,000 metric tons by 1983, with production from these mines dropping to 200,000 metric tons in 1993.

ANALYSIS OF RECENT DOMESTIC COPPER PRICES, COSTS, AND DEMAND

Copper Price and Capital and Operating Cost

Since 1965, the price of copper has increased from \$0.35 to \$0.67 per pound, an increase of 4.7 percent compounded annually. However, in constant 1978 dollars, copper price has actually decreased. This is illustrated in figure 10. Using the implicit price deflator for gross national product,

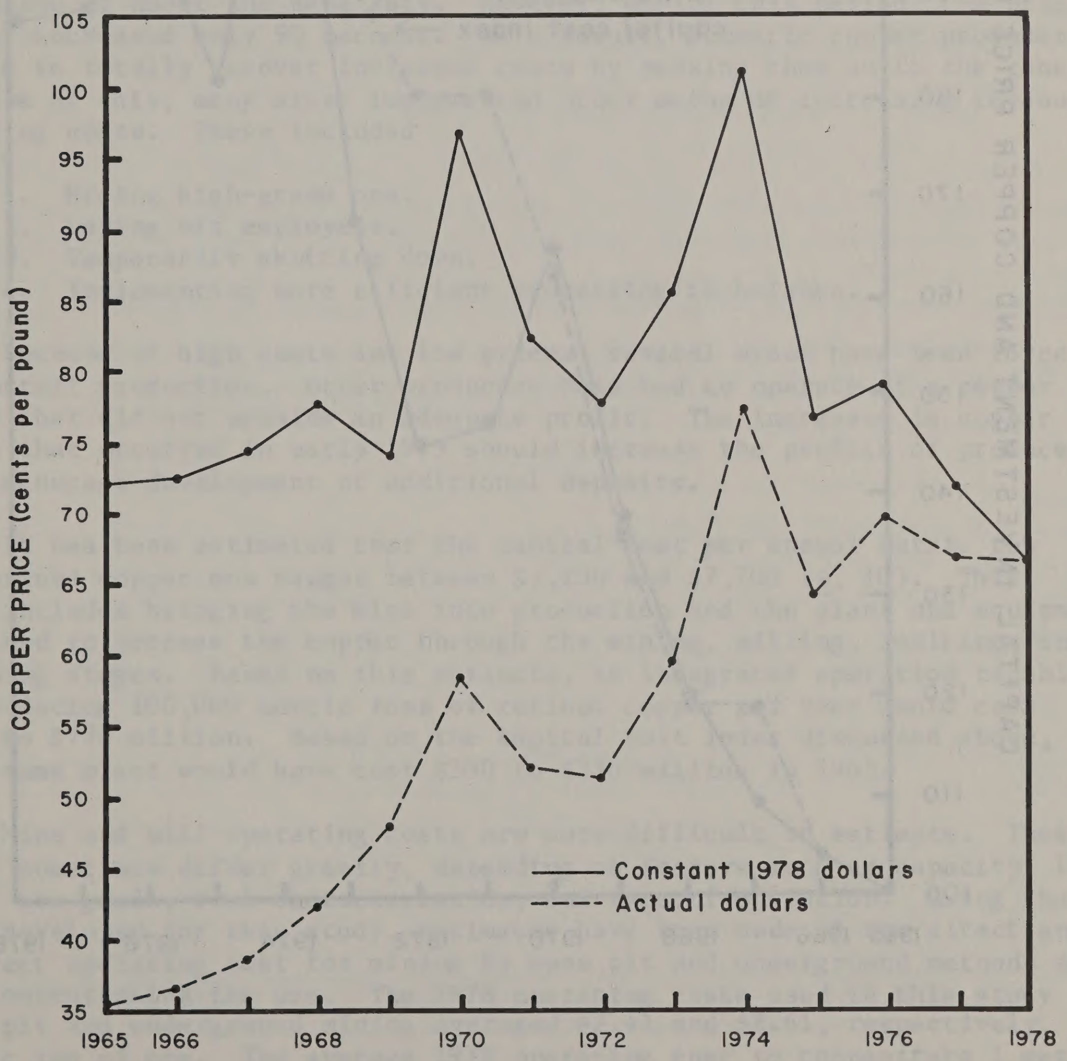

FIGURE 10. - Average annual copper price in actual dollars and in constant 1978 dollars.

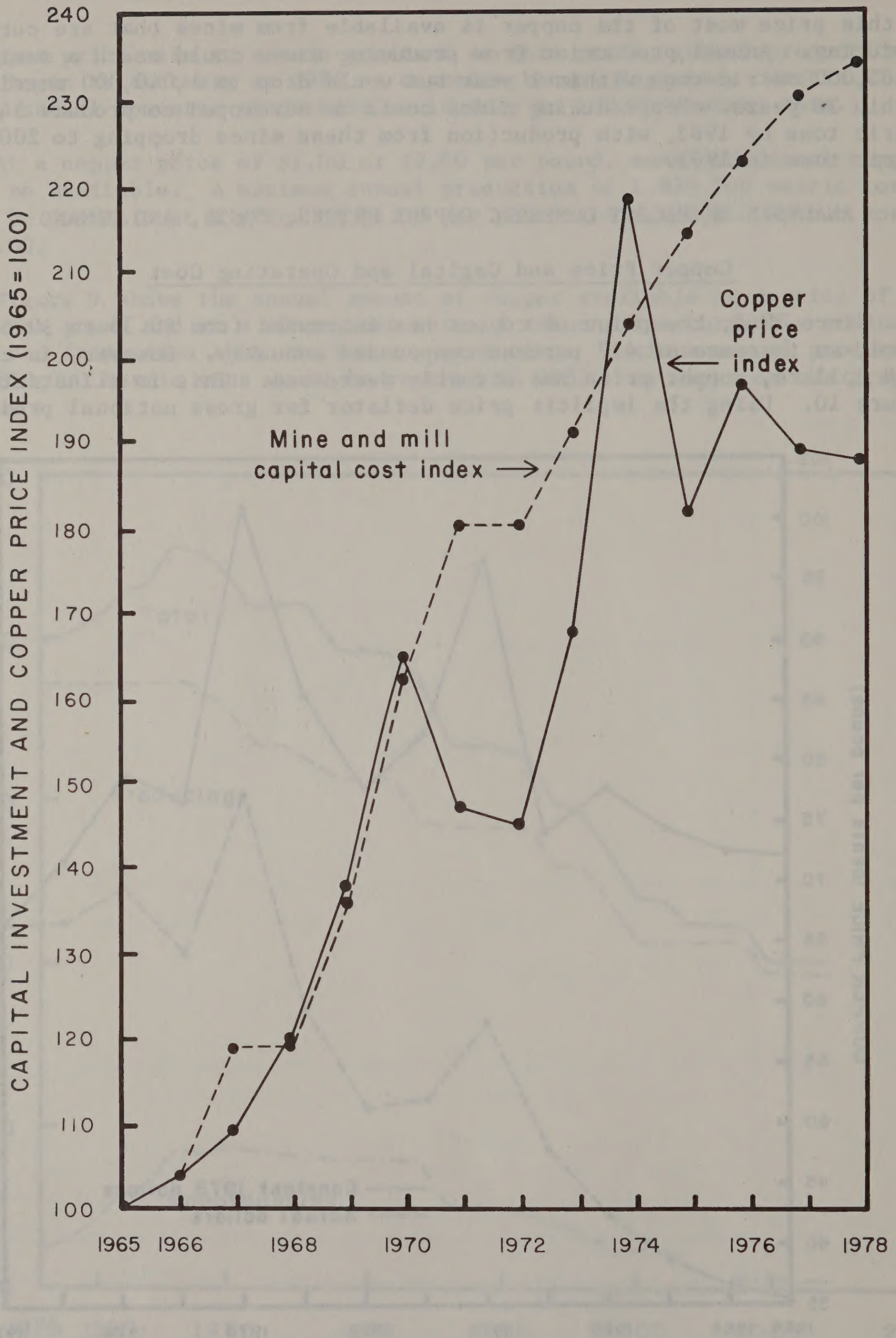

FIGURE 11. - Comparison of copper price index and mine and mill capital cost index.

average annual copper price was converted to constant 1978 dollars (9). As shown on the curve, the average annual constant dollar price of copper rose from $0.72 per pound in 1965 to a high of $1.01 in 1974, and then dropped to a low of $0.67 in 1978.

A comparison was also made between copper price and mine and mill capital cost. The year 1965 was established as the base year, and an index of 100 was assigned. Indexes for copper price were determined by dividing the actual dollar price for each year by the average 1965 price and multiplying by 100. Indexes for mine and mill capital costs were determined using the MAS cost-updating method (8). Cost indexes for mine and mill capital cost were calculated and averaged to arrive at the indexes used in this study. Results are shown in figure 11.

Between 1965 and 1978, mine and mill capital costs increased 135 percent, an average of 6.3 percent compounded annually. Mine and mill operating costs increased at about the same rate. However, during this period, the price of copper increased only 90 percent. As a result, domestic copper producers were unable to totally recover increased costs by passing them on to the consumer. Because of this, many mines implemented other means of increasing revenues or lowering costs. These included

1. Mining high-grade ore.
2. Laying off employees.
3. Temporarily shutting down.
4. Implementing more efficient processing techniques.

Because of high costs and low prices, several mines have been forced to curtail production. Other producers have had to operate at a copper price that did not provide an adequate profit. The increases in copper price that occurred in early 1979 should increase the profits of producers and encourage development of additional deposits.

It has been estimated that the capital cost per annual metric ton of refined copper now ranges between $7,200 and $7,700 (4, 10). This cost includes bringing the mine into production and the plant and equipment required to process the copper through the mining, milling, smelting, and refining stages. Based on this estimate, an integrated operation capable of producing 100,000 metric tons of refined copper per year would cost $720 to $770 million. Based on the capital cost index discussed above, this same plant would have cost $300 to $330 million in 1965.

Mine and mill operating costs are more difficult to estimate. These costs sometimes differ greatly, depending on factors such as capacity, location, ore grade, rock characteristics, and type of operation. Using the data developed for this study, estimates have been made of the direct and indirect operating cost for mining by open pit and underground methods and for concentrating the ore. The 1978 operating costs used in this study for open pit and underground mining averaged $2.41 and $8.61, respectively, per metric ton of ore. The average 1978 operating cost to concentrate 1 metric ton of ore by basic flotation methods was $2.79.

Environmental Costs

According to industry information, pollution control expenditures have added significant costs to the copper industry in recent years. Most of these expenditures have been for the purchase of pollution control equipment at copper smelters. Since 1969, the Cities Service Co. has spent $48 million for pollution control systems at the Copperhill operation (5). The Inspiration Consolidated Copper Co. has spent $70 million on pollution control equipment at its Inspiration, Ariz., smelter (6).

Several sources have estimated that expenditures for pollution control equipment have added 15 cents per pound to the cost of producing refined copper (1, 10). Because of the depressed copper price in recent years and the oversupply of copper, producers have been unable to pass this added cost on to the consumer. Unlike the domestic industry, most foreign producers have not had to implement pollution control measures. As a result, copper produced in other countries has a cost advantage over U.S. production.

Domestic Demand for Copper

Between 1969 and 1978, 67 percent of U.S. copper demand, excluding stock changes, was met from domestic mine production, 21 percent from old scrap, and 12 percent from net imports. During these years, total U.S.

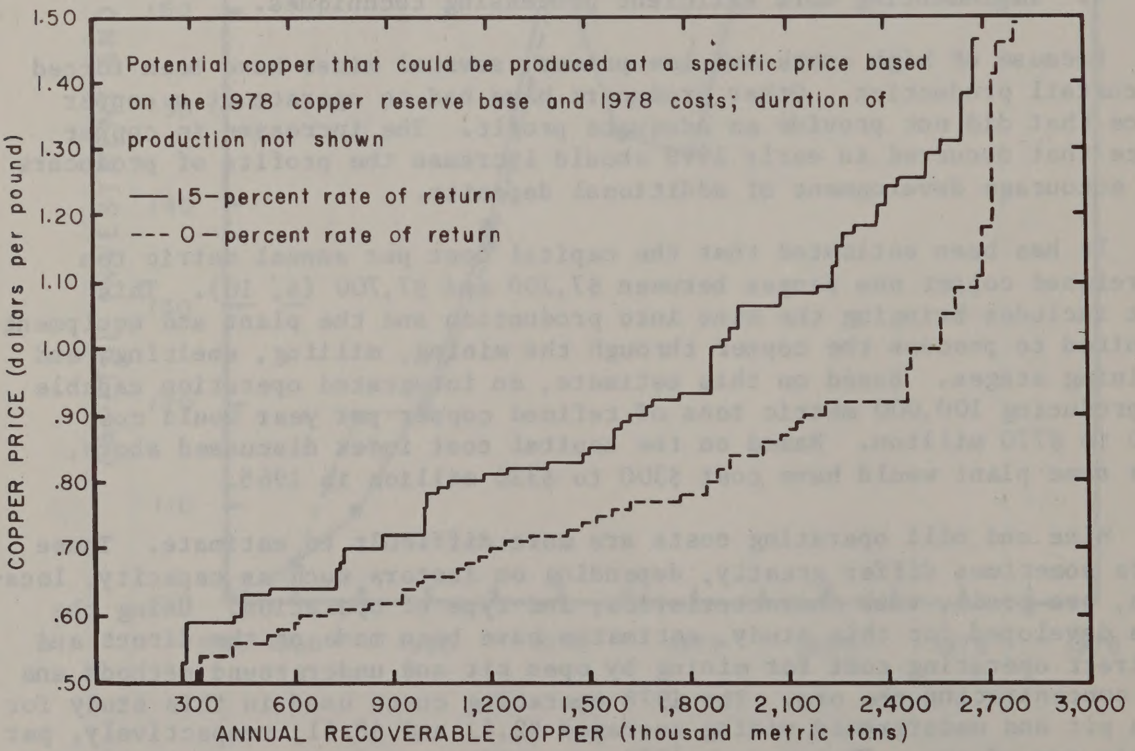

FIGURE 12. - Annual recoverable copper available from domestic deposits over a copper price range of $0.50 to $1.50 per pound.

demand for copper averaged 2,012,000 metric tons per year. Of this amount, 1,337,000 metric tons was from domestic production, 427,000 metric tons from scrap, and 248,000 metric tons from net imports (7).

Using the curves derived in this study, the copper price required to meet various levels of supply can be predicted. Figure 12 shows the available annual supply of recoverable copper at prices from $0.50 to $1.50. Forty-five deposits would be able to produce at a price of $1.00 and receive a rate of return of at least 15 percent.

The break-even copper price (based on a weighted average of capacity and cost for each property) was $0.66 per pound in 1978. This was about equal to the average market price during the year. In January 1978, copper was selling for $0.64 per pound. Analysis indicates that at this price, only 12 properties could produce and receive at least a 15-percent rate of return. The combined annual recoverable copper available from these 12 deposits is only 733,000 metric tons. At the beginning of July 1979, copper was selling for about $0.85 per pound. At this price, assuming no increase in costs of production, 22 additional properties could produce and receive at least a 15-percent rate of return.

For U.S. producers to meet the average 1969-78 annual domestic production of 1,337,000 metric tons and receive at least a 15-percent rate of return on their capital investment, a copper price of $0.82 per pound is required ($0.72 at break-even). If the United States were to produce the additional 248,000 metric tons that were imported each year over this period, a copper price of $0.88 per pound would be required at a 15-percent rate of return ($0.76 at break-even).

CONCLUSIONS

Seventy-three domestic copper properties have been analyzed to determine the quantity of copper available from each deposit and the copper price required to provide each operation with 0- and 15-percent rates of return. The 1978 domestic copper reserve base is 92 million metric tons of copper. Of this amount, an estimated 74 million metric tons are recoverable using current technology.

A copper price of $2.07 per pound would be required if all properties, producing and nonproducing, were to at least break even. This price increases to $3.81 for the properties to receive at least a 15-percent rate of return. The average break-even copper price for properties producing in 1978, $0.66 per pound, was about equivalent to the average selling price for the year. At this price, analyses indicate that only 25 properties could either produce at break-even or receive an operating profit. Of these properties, only 12 could receive at least a 15-percent rate of return.

Annual domestic copper production from 1969 to 1978 averaged 1,337,000 metric tons. Based on the results of this study, in order to produce at this level and receive at least a 15-percent rate of return, a copper price of $0.82 per pound is required. If the United States were to produce the additional 248,000 metric tons that were imported each year over this period, a copper price of $0.88 would be necessary.

Analysis has indicated that increases in copper price are required in order for many domestic deposits to continue to produce. Many U.S. producers cannot continue to operate at a copper price that has not kept pace with inflated operating and capital costs. Assuming copper demand and other market conditions warrant it, the increases in copper price that occurred in early 1979 will help provide the additional revenue necessary for many operations to continue producing and should encourage companies to begin developing other properties.

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APPENDIX

TABLE A-1. - Ownership and control of domestic copper properties[1]
(Information as of April 1979)

Mine name	Map index No.[2]	Domain	Type of mineral holding	Owner/operator	Status	Percentage of ownership
Alaska:						
Arctic Camp	1	Bureau of Land Management.	Located claim	Bear Creek Mining Co. (subsidiary of Kennecott Copper Corp.).	Owner-operator	100
Bond Creek	2	...do	...do	...do	...do	100
Orange Hill	2	...do	Located claim - patented	Wallace McGregor	...do	100
Bornite	3	...do	Located claim	Bear Creek Mining Co. (subsidiary of Kennecott Copper Corp.).	...do	100
Brady Glacier	4	National Monument.	Located claim - patented	Newmont Exploration Ltd	Operator	0
				Numerous miscellaneous owners	Owner	100
Yakobi Island	5	National Forest	Located claim	Inspiration Development Co	Owner-operator	100
Arizona:						
Bagdad	6	Private	Patented	Cyprus Mining Corp	...do	100
Bluebird	7	National Forest	...do	Ranchers Exploration and Development Corp.	...do	100
Casa Grande	8	Private	Leasing - private ownership	1. Casa Grande Copper Co	Operator	0
				2. The Hanna Mining Co	Owner	50
				3. Getty Oil Co	...do	50
Christmas	9	Federal	Located claim	Inspiration Consolidated Copper Co	Owner-operator	100
Copper Basin	10	Private	Patented - Federal lease - fee ownership.	Phelps Dodge Corp	...do	100
					...do	100
Cyprus Johnson	11	...do	Patented	Cyprus Johnson Copper Co	...do	100
Dubacher Canyon	12	...do	State lease - private lease	Occidental Minerals Corp	Owner	100
Esperanza	13	Private	Patented - located claim	Duval Corp. (subsidiary of Pennzoil Co.).	Owner-operator	100
Florence Conoco	14	State	Located claim - other - state lease.	Continental Oil Co. Minerals Inc	...do	100
Helvetia East	15	Federal	Patented - fee ownership - located claim.	ANAMAX Mining Co	Owner	100
Helvetia West	16	Private	Patented - located claim	Inspiration Consolidated Copper Co	Owner-operator	100
Inspiration	17	...do	...do	...do	...do	100
Lakeshore	18	Indian Reservation.	Private lease	Noranda	Owner	100
Magma (Superior)	19	Private	Patented - fee ownership	Magma Copper Co. (subsidiary of Newmont).	Owner-operator	100
Metcalf	20	...do	Fee ownership	Phelps Dodge Corp	...do	100

Miami East.......	21...	...do............	Patented.....................	Cities Service Co.....................	...do...........	100
Miami Leach......	22...	...do............	...do........................	...do.................................	...do...........	100
Mineral Park.....	23...	...do............	...do........................	Duval Corp. (subsidiary of Pennzoil Co.).	...do...........	100
Mission San Xavier.	24...	Mixed............	Patented - lease............	ASARCO, Inc..........................	...do...........	100
Morenci..........	25...	Private..........	Fee ownership................	Phelps Dodge Corp.....................	...do...........	100
New Cornelia (Ajo).	26...	...do............	Patented - fee ownership.....	...do.................................	...do...........	100
Oracle Ridge.....	27...	...do............	Patented - located claim.....	1. Continental Copper - Continental Materials Corp.	...do...........	55
				2. Union Copper - Union Miniere.......	Owner...........	45
Ox Hide..........	28...	Mixed............	Located claim................	Inspiration Consolidated Copper Co....	Owner-operator..	100
Palo Verde.......	29...	Private..........	State lease - located claim..	1. ANAMAX Mining Co...................	Owner...........	50
				2. ASARCO, Inc........................	Owner-operator..	50
Peacock..........	30...	...do............	Private lease................	Producers Minerals Corp..............	...do...........	100
Pima.............	31...	Mixed............	Patented - state lease.......	1. Cyprus Mines Inc...................	...do...........	50
				2. Utah International (subsidiary of G.E. Corp.).	Owner...........	25
				3. Union Oil Corp.....................	...do...........	25
Pinto Valley.....	32...	Private..........	Patented - located claim.....	Cities Service Co.....................	Owner-operator..	100
Ray..............	33...	...do............	Patented - fee ownership.....	Kennecott Copper Co...................	...do...........	100
Red Mountain.....	34...	National Forest..	Federal lease................	Kerr-McGee Corp.......................	...do...........	100
Sacaton, East and West.	35...	State............	State lease - fee ownership..	ASARCO, Inc..........................	...do...........	100
Safford Inspiration (Sanchez).	36...	Private..........	Fee ownership - patented.....	Inspiration Consolidated Copper Co....	Owner...........	100
Safford Kennecott.	37...	...do............	...do........................	Kennecott Copper Co...................	...do...........	100
Safford Phelps Dodge.	38...	...do............	...do........................	Phelps Dodge Corp.....................	Owner-operator..	100
San Manuel Kalamazoo.	39...	...do............	Patented - state lease.......	Magma Copper Co. (subsidiary of Newmont).	...do...........	100
Sierrita.........	40...	...do............	Patented - located claim.....	Duval Sierrita Corp. (subsidiary of Pennzoil Co.).	...do...........	100
Silver Bell......	41...	...do............	Patented.....................	ASARCO, Inc..........................	...do...........	100
Twin Buttes......	42...	...do............	Patented - located claim.....	ANAMAX Mining Co......................	...do...........	100
Van Dyke.........	43...	Municipality.....	Private lease................	Occidental Minerals Corp..............	...do...........	100
Vekol Hills......	44...	Indian Reservation.	Federal lease................	1. Newmont Mining Corp................	...do...........	51
				2. Superior Oil Co....................	Owner...........	49
California:						
Lights Creek.....	45...	Mixed............	Located claim - patented - private lease.	Placer AMEX, Inc......................	Owner-operator..	100

TABLE A-1. - Ownership and control of domestic copper properties[1] - Continued

Mine name	Map index No.[2]	Domain	Type of mineral holding	Owner/operator	Status	Percentage of ownership
California - continued:						
Walker	46	...do	Located claim - patented	Calicopia Corp	Owner	100
				Continental Oil Co	Operator	0
				AMAX, Inc	...do	0
Michigan:						
Presque Isle	47	State Park	Private lease - minerals only.	1. AMAX, Inc	Owner-operator	85
				2. Copper Range Co. (subsidiary of Louisiana Land and Exploration).	Owner	15
White Pine	48	Private	Private lease - fee ownership - minerals only.	Copper Range Co. (subsidiary of Louisiana Land and Exploration).	Owner-operator	100
Minnesota:						
Minnamax	49	Federal	State lease - private lease - Federal lease.	AMAX, Inc	...do	100
Ely Spruce	50	...do	Private lease - Federal lease - fee ownership.	International Nickel Co	...do	100
Montana:						
Butte	51	Private	Private lease - patented - fee ownership.	The Anaconda Co. (subsidiary of ARCO).	...do	100
Heddleston	52	National Forest	Patented - located claim - private lease.	...do	...do	100
Stillwater	53	Mixed	Patented - located claim - Federal lease.	...do	...do	100
Troy	54	National Forest	Patented - located claim	1. Bear Creek Mining Co. (subsidiary of Kennecott Copper Corp.).	Owner	100
				2. ASARCO, Inc	Operator	0
Nevada:						
Hall	55	Mixed	Located claim - patented	The Anaconda Co. (subsidiary of ARCO).	Owner	100
New Ruth	56	Private	Patented	Kennecott Copper Corp	Owner-operator	100
Victoria	57	...do	...do	The Anaconda Co. (subsidiary of ARCO).	...do	100
Yerington	58	...do	...do	...do	...do	100

New Mexico:						
Chino...........	59...	...do...........	Fee ownership...............	Chino Mines (Division of Kennecott Copper Corp.).	...do...........	100
Continental Underground.	60...	...do...........	Patented - fee ownership.....	UV Industries Inc....................	...do...........	100
Continental Surface.	61...	...do...........	Fee ownership - private......	...do................................	...do...........	100
Hillsboro (Copper Flat).	62...	...do...........	Fee ownership - private lease.	Quintana Minerals Corp...............	...do...........	100
Nacimiento.......	63...	Mixed...........	Patented - located claim.....	Earth Resources Co...................	...do...........	100
Pinos Altos......	64...	National Forest..	Located claim - patented - fee ownership.	Exxon Minerals Co. U.S.A. (subsidiary of Exxon Corp.).	Owner...........	100
Tyrone...........	65...	Private.........	Fee ownership - patented.....	Phelps Dodge Corp....................	Owner-operator..	100
Tennessee:						
Copperhill.......	66...	...do...........	Fee ownership...............	Cities Service Co. - Copperhill Operations.	...do............	100
Utah:						
Bingham..........	67...	Private.........	Patented....................	Kennecott Copper Corp................	Owner-Operator..	100
Carr Fork........	68...	...do...........	...do.......................	The Anaconda Co. (subsidiary of ARCO).	...do...........	100
Washington:						
Sunrise..........	69...	National Forest..	Located claim - state lease.	International Brenmac Development Corp.	...do...........	100
Wisconson:						
Crandon..........	70...	Private.........	Fee ownership - private lease - minerals only.	1. Exxon Minerals Co. U.S.A. (subsidiary of Exxon Corp.).	...do...........	10
				2. Chicago and Northwestern Transportation Co.	Owner...........	35
				3. Conner Forest Industries..........	...do...........	35
				4. Charles Mihalko...................	...do...........	20
Flambeau.........	71...	...do...........	Fee ownership...............	Flambeau Mining Corp. (Division of Kennecott Copper Co.).	Owner-operator..	100
Pelican River....	72...	...do...........	Fee ownership - private lease - minerals only	1. Noranda Exploration Inc...........	Operator........	0
				2. Consolidated Paper Inc............	Owner...........	100
Wyoming:						
Kirwin...........	73...	...do...........	Patented - located claim	AMAX, Inc............................	...do...........	100

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[1] Additional property information is given in table 3.

[2] Map index numbers refer to numbers in figure 3.

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